PCT/EP02/50001

Rec'd PCT/PTO 13 JUL 2004

10/501416

Europäisches Patentamt

European Patent Office

Office européen des brevets

REC'D 14 FEB 2003

WIPO PCT

Bescheinigung

Certificate

Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

02075226.7

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

BEST AVAILABLE COPY

Anmeldung Nr:
Application no.: 02075226.7
Demande no:

Anmeldetag:
Date of filing: 18.01.02
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

Koninklijke Philips Electronics N.V.
Groenewoudseweg 1
5621 BA Eindhoven
PAYS-BAS

Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Dual-stack and multi-stack optical data storage medium for write once recording

In Anspruch genommene Prioriät(en) / Priority(ies) claimed /Priorité(s) revendiquée(s)
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/
Classification internationale des brevets:

G11B7/00

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of filing/Etats contractants désignées lors du dépôt:

AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR

Dual-stack and multi-stack optical data storage medium for write once recording.

The invention relates to a dual-stack optical data storage medium for write-once recording by means of a focused laser-light beam emanating from a laser-light beam source, said medium having at least one substrate carrying:
-a first recording stack, named L_0, comprising a recordable type recording layer, said first recording stack being present at a position closest to the source of focused laser-light beam,
-a second recording stack, named L_1, comprising a recordable type recording layer,said second recording stack being present at side of the first recording stack opposite from the side of the laser-light beam source during recording.
-a transparent spacer layer between the first and the secondrecording stack having a thickness larger than the depth of focus of the focused laser-light beam.

The invention further relates to a multi-stack optical data storage medium for write-once recording by means of a focused laser-light beam emanating from a laser-light beam source, said medium having at least one substrate carrying:
-a first recording stack, named L_0, comprising a recordable type recording layer, said first recording stack being present at a position closest to the focused laser-light beam source,
-a second recording stack, named L_1, comprising a recordable type recording layer, said second recording stack being present at side of the first recording stack opposite from the side of the laser-light beam source during recording,
-a transparent spacer layer between the first and the second recording stack having a thickness larger than the depth of focus of the focused laser-light beam,
-a further recording stack, named L_n where n is an integer number larger than 1, comprising a recordable type recording layer, said further recording stack being present at a side of the second recording stack opposite from the side of the laser-light beam source during recording, and
-a further transparent spacer layer for separating said further recording stack from the L_{n-1}-stack.

Regarding the market for optical recording, it is clear that the most important and successful format so far is a write-once format, CD-R. Although the take-over in importance by CD-RW has been predicted since a long time, the actual market size of CD-R media is still at least an order of magnitude larger than for CD-RW. Furthermore the most important parameter for drives is the maximum write speed for R-media, not for RW. Of course, a possible shift of the market to CD-RW is still possible, e.g. because of Mount Rainier for CD-RW. However, the R-format has been proven very attractive due to its 100% compatibility.

Next to the DVD+RW standard recently a new DVD+R standard was developed. The new DVD+R standard gets increasing attention as an important support for DVD+RW. A possible scenario is that the end customers have become so familiar with

an optical write-once format that they might accept it more easily than a re-writable format.

An issue for both the R and RW formats is the limited capacity and therefore recording time because only single-stacked media are present (for DVD-Video, dual stacked media have a considerable market share). A dual-layer DVD+RW disc is probably feasible. However, it has become clear that a fully compatible disc, i.e. within the reflection and modulation specification of the dual-layer DVD-ROM, is very difficult to achieve and requires at least a major breakthrough for the phase-change material properties. Without a full compatibility, the success of a dual-layer DVD+RW in the market is questionable.

It is an object of the invention to provide an optical data storage medium of the type mentioned in the opening paragraph which is compatible with the existing DVD-ROM standard.

It is a second object of the invention to provide an optical data storage medium of the type mentioned in the second paragraph in which the L_0, L_1 and L_n- stack each have a reflection level of the incoming laser-light beam of larger than 5% when focused at the recording layer of said L_0, L_1 and L_n- stack.

The first object is achieved in that a dual-stack DVD+R disc based on dye-technology can in principle overcome the reflection-problem of the phase-change DVD+RW dual stack disc. The typical single stack DVD+R has a reflectivity of 50% and a modulation of 60%; these values are very close to the single stack DVD-ROM specification. The starting point for developing a dual-stack R-disc is thus much more favourable than for RW media. The dye material intrinsically has a high transmission. In combination with a metal mirror, a high reflectivity can be achieved. Thus, recording is possible with a relatively low absorption in the dye layer.

Typical dyes that can be used are (phthalo)cyanine-type, azo-type, squarylium-type, or other organic dye material having the desired properties.

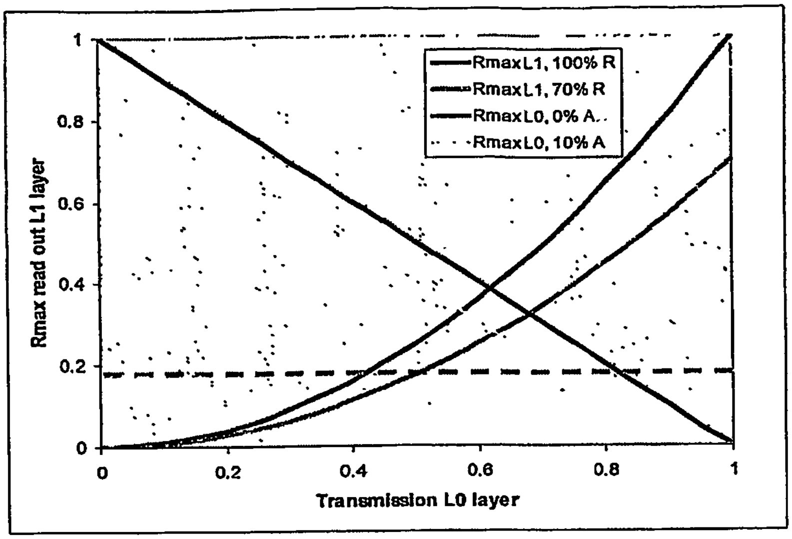


Figure 1: Maximum attainable reflection of lower recording stack L1 as a function of the transmission of upper recording stack L0. The lines for absorption A=0 are the theoretical limit, a typical absorption for a dye layer would be 10%. The effective reflection of 18% per stack as required by the DVD standard is indicated by the red line.

Figure 1 shows that a compatible dual stack DVD+R disc is in principle possible when assuming reasonable numbers for transmission and absorption of dye layers. A reflection of larger than 18% per stack is possible if the transmission of the upper recording stack L0 is between 50% and 75%; the intrinsic reflection of the lower recording stack L1 should then be in the range 60% – 80%. Figure 2 illustrates this fact in more detail.

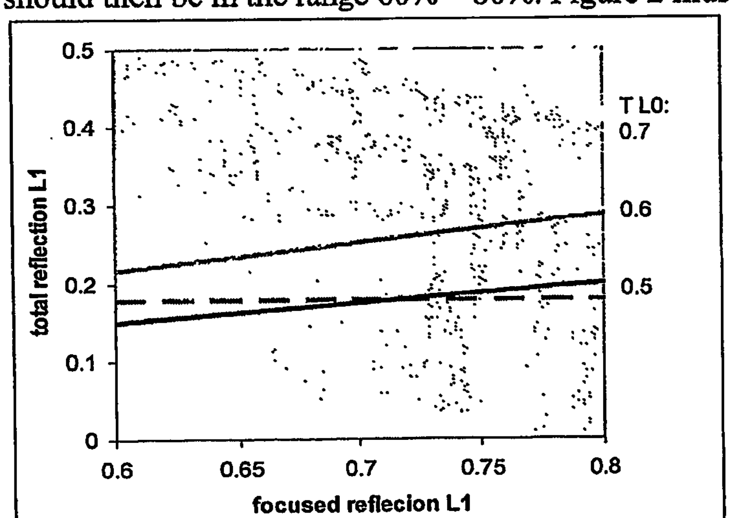


Figure 2: Effective total reflection form L1 as a function of the intrinsic reflection of L1; examples for three different Transmission values of L0 are shown.

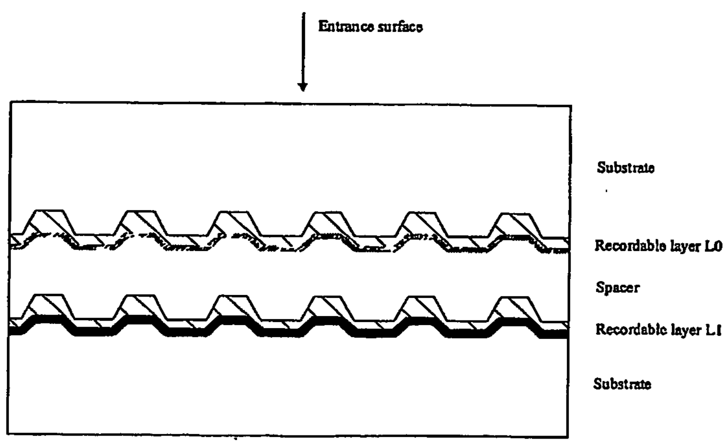
Possibilities for Implementation

A straightforward approach is a completely dye-based dual-stack DVD+R consisting of two bonded 0.6mm substrates. Each substrate carries one recording stack. In this approach, there is a particular problem for each of the two recording stacks to be solved.

- Upper recording stack, L0: This stack has to have a high transmission of about 50%. Apart from that, the stack structure (substrate-dye-mirror-lacquer) can be similar to a standard DVD+R. Consequently, the substrate (groove depth, geometry) would be similar to a standard DVD+R substrate. The mirror can be a very thin Ag-layer or maybe some other dielectric mirror (use candidate-list of dual-stack DVD+RW mirrors). Thus, test-discs for the L0-layer are probably not too difficult to produce. However, the thermal properties of such a disc and probably also details in the recording mechanism are different from a standard DVD+R. The major investigation effort would be to study the recording properties of the L0-stack and to find the best mirror material.
- Lower recording stack, L1: The reflectivity requirements for this stack are similar to a single stack disc, i.e. maximum reflectivity and modulation. However, there is an important difference: the stack structure is inverted[1] (lacquer-dye-mirror-substrate). Therefore, groove depth and geometry have to be different due to the so-called levelling of the spin-coated dye. More importantly, also the recording mechanism will be affected for this inverted disc structure. A considerable part of the recording effect is produced by the local deformation of poly-carbonate substrate. A metal heat sink between dye and substrate changes the thermal boundary conditions. The research effort has to be both on the stack structure including the mirror materials and the recording properties.

Implementations

Type 1:

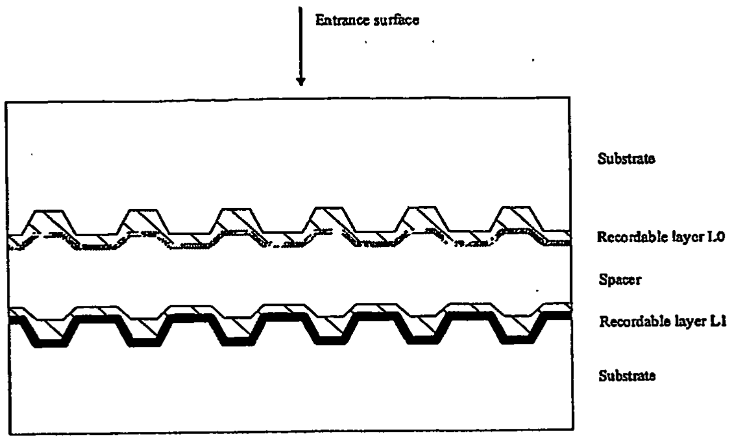


Type 1

[1] The issue of the inverted stack is identical for a DVR-R.

An optical recording stack (L0), optically semi-transparent at laser wavelength, is applied to a transparent, pre-grooved substrate. (specific L0 stack designs are discussed in different ID).
A transparent spacer is attached to the L0 stack. The spacer either contains pregrooves for L1 or pregrooves for L1 are mastered into the spacer after application to L0. Second recording stack L1 is deposited on the grooved spacer (specific L1 stack designs will be discussed in different ID). Finally, a flat (no grooves) counter substrate is applied.

Type 2:



Type 2

An optical recording stack (L0), optically semi-transparent at the laser wavelength, is applied to a transparent, pre-grooved substrate. (specific L0 stack designs are discussed in different ID). A second optical recording stack L1, reflective at the laser wavelength, is applied to a second transparent pre-grooved substrate (specific L1 stack designs will be discussed in different ID). This substrate with L1 is attached to the substrate with L0 with a transparent spacer layer in between.

Preferred spacer-layer thickness for both disc types is 40 µm to 70 µm..

The upper L0 stack of a recordable dual-stack DVD disc should have high transparency in order to be able to address the lower lying L1 stack. At the same time, L0 should have a reflectivity of at least 18% in order to meet the DVD+RW specification. Because of these requirements different stack designs are needed compared to the single-stack DVD+R disc which usually consists of a sole dye-layer on top of a thick metal layer. In this invention four possible classes of stack designs for L0 are proposed that meet the above qualifications. In order of appearance, these stacks are: dye-only, dye + thin-metal layer, dye + dielectric interference-layer, dye + thin-metal + dielectric interference-layer. The stacks proposed here are not restricted to use in DVD+R-DL and can be applied in any (multi-stack) organic-dye based optical recording medium. The thickness and optical constant ranges specified below, however, are such as to meet the requirements for an L0-stack of a DVD+R-DL disc.

DVD+R-DL embodiment:

Remark: everywhere in this document where dual-layer (DL) is mentioned actually dual-stack is meant.

A DVD+R DL disc would consist of any combination of L0-stack, L1-stack.

One specific embodiment would be:

Disc of type 2, with L0 embodiment stack 4b (95 nm dye/ 10 nm Ag/ 55 nm $ZnS\text{-}SiO_2$) and L1 embodiment stack 6 (15 nm Ag/ 130 nm dye/ 100 nm Ag), having spacer thickness of 55 μm.

Effective reflection from L0 is 28 %, effective reflection (through L0) from L1 is 21%.

By using dyes that are almost transparent at the recording wavelength, which is typically the case in recordable optical media such as CD-R and DVD+R, recording stacks with high transmission suitable for multi-stack media can be fabricated. Below follow four different stack designs, in which an organic dye is incorporated, that have a high transparency (in order to enable addressing lower-lying stacks) and finite reflectivity (necessary for read-out). The parameter ranges claimed in this ID are tuned such as to meet the specifications for the upper recording stack L0 in a recordable dual-stack DVD disc:

$R \geq 18$ %,

$T \geq 50$ %.

The lower limit for T is not strict (if L1 is very highly reflective [R > 80%] a somewhat lower T may still work) but does indicate a practical range.

To understand the thickness ranges proposed for the different stacks below, it is helpful to note that:

(i) The reflection and transmission of the stacks are periodic in $\lambda/2n_d$.

(ii) The extrema in reflection and transmission of the stacks coincide [due to the intrinsic high transparency of the dyes ($k_d < n_d$)].

1. dye-only

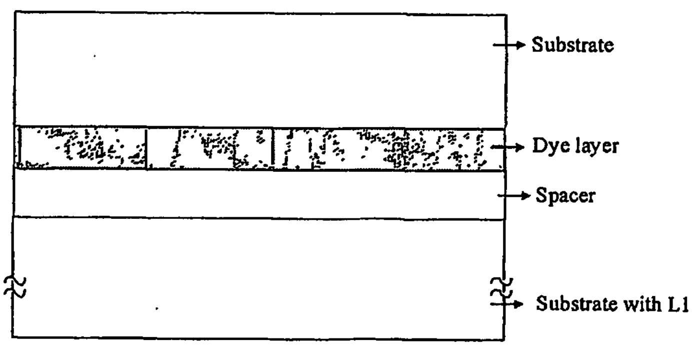


Figure 3: Schematic layout of dye-only L0 stack design

For common values of the dye's optical constants ($n_d < 3$, $k_d < 0.3$) sufficiently high transmission can be achieved; the reflectivity therefore determines the required optical parameters and layer thickness.

Figure 4 shows the calculated reflectivity of a dye-only stack; the dashed red line indicates the specified R = 18% of a DVD+RW drive.

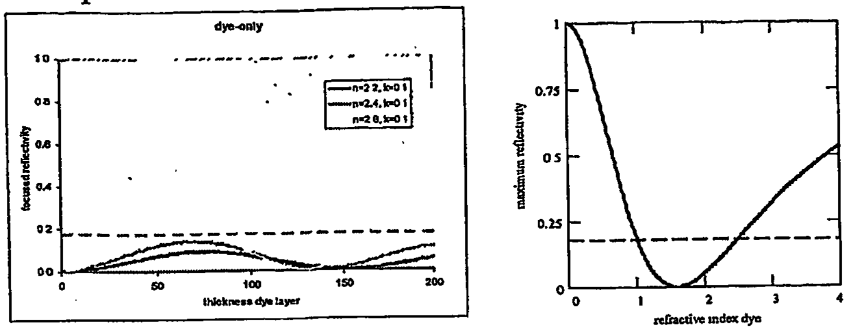


Figure 4: *The left-hand figure shows the calculated reflectivity as function of the dye's thickness for three values of the dye's refractive index. The optima in reflection are located at thickness of* $(\frac{1}{2} + p)*\lambda/2n_d$ *with p an integer. The right-hand figure shows the maximally attainable reflectivity of a single dye layer in an optical disc (dye is embedded in* $n_0 = 1.6$ *polycarbonate background). The dashed red line indicates the lower R-limit.*

It follows from Figure 4 that in order to get a reflectivity of at least 18%, the dye's refractive index n_d should be sufficiently large (or small):

(1) $n_d \geq 2.5$ or $n_d \leq 1.0$

The latter is however less likely to be met in practice.

The optimal layer thickness d is at the first or second maximum in reflectivity, the preferred layer thickness is then:

$\lambda/8n_d \leq d \leq 3\lambda/8n_d$ (1st max)

$5\lambda/8n_d \leq d \leq 7\lambda/8n_d$ (2nd max)

<u>Pro's:</u> high transparency

very simple stack design

2. dye + thin metal layer

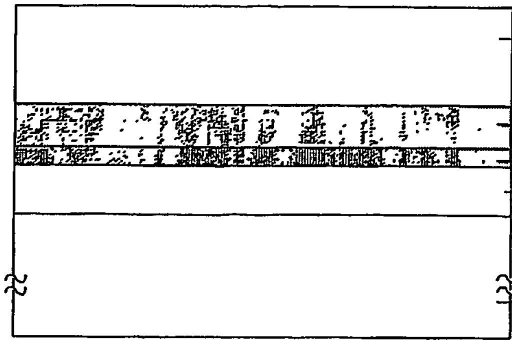


Figure 5: Schematic layout of dye+thin metal layer stack design for L0.

For this stack, the dye is on top of a thin metal layer (the other way around is not considered here). The thin metal layer serves as a semi-transparent mirror to increase the reflectivity.

A maximum thickness and suitable material must be specified to keep the transmission of the metal layer sufficiently high. For the thin metal layer e.g. Ag, Au, Cu, Al, or alloys thereof, or doped with other elements, can be used. In order to obtain a sufficiently transparent stack ($T \geq 50$ %), the preferred thickness of the metal layer is:

(2) $d_m \leq 25$ nm

The optimum dye-layer thickness is determined by both the maxima in transmission and reflection.
The presence of the thin metal layer introduces an additional phase shift $\Delta \sim 1/8$ to $1/4$ in the extrema of R and T; for this stack design the maxima in R and T are located at: Max(R) $\rightarrow \lambda/2n_d\,(p - \Delta)$, Max(T) $\rightarrow \lambda/2n_d\,(p + 1/2 - \Delta)$.
Only the thickness range around the first reflection maximum is suitable because of the decreasing transmission for larger dye thickness. The lower limit for d is defined by the maximum in T: LL = Max(R) – 1/2 period = $\lambda/8n_d$. The upper limit for d is defined by 2[nd] Max(T) – 1/8 period = Max(R) + 3/8 period = $5\lambda/8n_d$ because for increasing thickness the reflectivity drops strongly. Thus, the preferred dye layer thickness range becomes:

(3) $\lambda/8n_d \leq d \leq 5\lambda/8n_d$

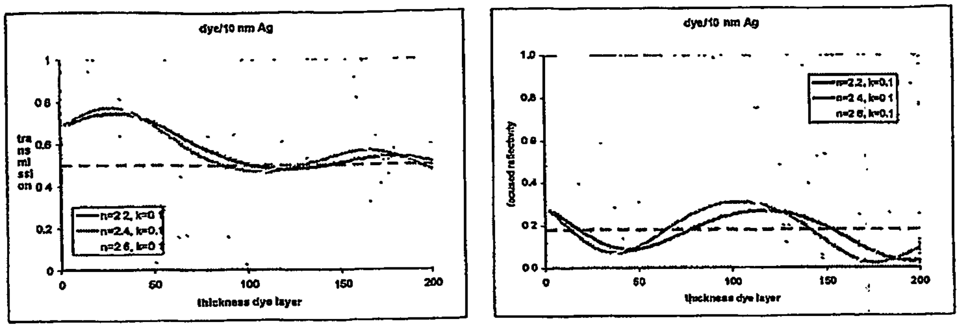


Figure 6: *On the left is plotted the transmission of a dye/thin-metal stack as a function of the dye's thickness for three values of the refractive index of the dye. On the right is shown the reflection of these same stacks as function of dye thickness. The dashed red line indicates the lower limits allowed for R and T. The maxima in R and minima in T are located at thickness $(p-\Delta)*\lambda/2n_d$, where p is an integer and $\Delta \sim 1/8$ to $1/4$. The minima in R and maxima in T are located at thickness $(p+\frac{1}{2}-\Delta)*\lambda/2n_d$.*

<u>Pro's:</u> good reflective properties
almost the same as "standard" single recording stack (similar recording behaviour expected)

3. dye + one interference layer

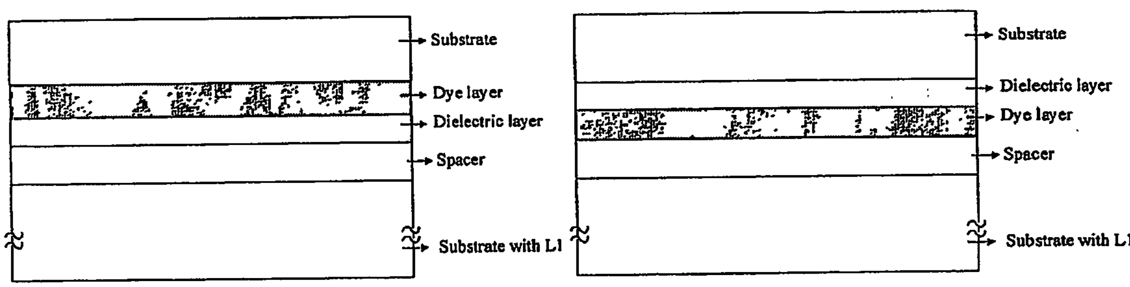


Figure 7: Schematic layout of L0 stack design dye + one interference layer. Left: dye on dielectric (dye/I stack, type a below). Right: dielectric on dye (I/dye stack, type b below).

This stack is based on the principle of a dielectric mirror. Since the dielectric I-layer is transparent, the requirements for dye- and I-layer thickness and optical constants follow from the reflectivity constraint.

The reflectivity is maximised when the interference layer is $\lambda/4n_I$ (or $3\lambda/4n_I$) thick and the dye layer $\lambda/4n_d$ (1[st] max) or $3\lambda/4n_d$ (2[nd] max).
The preferred range of the interference layer thickness is:

(4) $\lambda/8n_I \leq d_I \leq 3\lambda/8n_I$

The preferred thickness range for the dye layer is:

(5) $\lambda/8n_d \leq d \leq 3\lambda/8n_d$ (1^{st} max)
(6) $5\lambda/8n_d \leq d \leq 7\lambda/8n_d$ (2^{nd} max)

Two cases of this type of stack can be discerned: (a) dye on top of I-layer and (b) I-layer on top of dye.

(a) dye/I stack
The optimum reflectivity is given by $R = [(1-(n/n_I)^2)/(1+(n/n_I)^2)]^2$.
To meet the reflectivity specification of R = 18%, the I-layer's refractive index can be calculated to be:

(7) $n_I \leq n_d/1.572$

(b) I/dye stack
The optimum reflectivity is given by $R = [(1-(n_I/n)^2)/(1+(n_I/n)^2)]^2$.
To meet the reflectivity specification of R = 18%, the I-layer's refractive index can be calculated to be:

(8) $n_I \geq n_d/0.636$

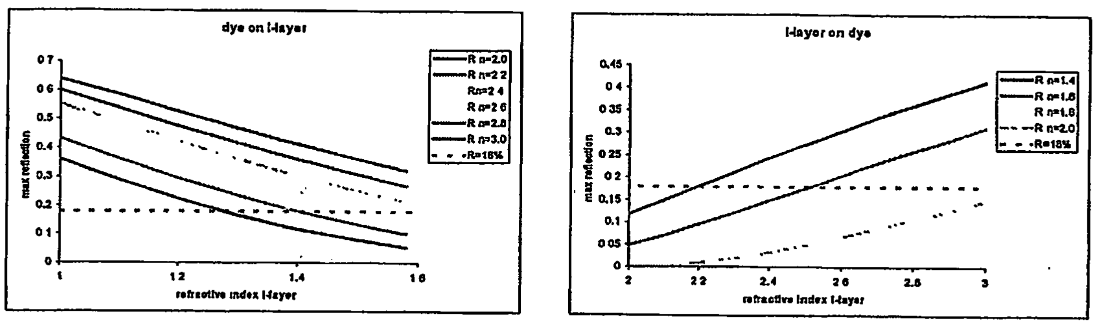


Figure 8: *In the left-hand graph the maximum reflectivity of a dye/interference-layer stack is shown as a function of the refractive index of the I-layer for five values of the dye's refractive index. The right-hand figure shows the maximum reflectivity of an interference-layer/dye stack as a function of the refractive index of the I-layer for four different values of the dye's refractive index. The dashed red line indicates the lower limits allowed for R.*

By adding more interference layers (with alternating high n and low n, and thickness around $\lambda/4n$) the reflective properties of the stack can be improved using less extreme values of the refractive indices of the I-layers. Obviously, the stack becomes more complicated then.

<u>Pro's</u> -sufficient reflection and high transmission
-relatively simple stack design

4. dye + thin metal layer + one interference layer

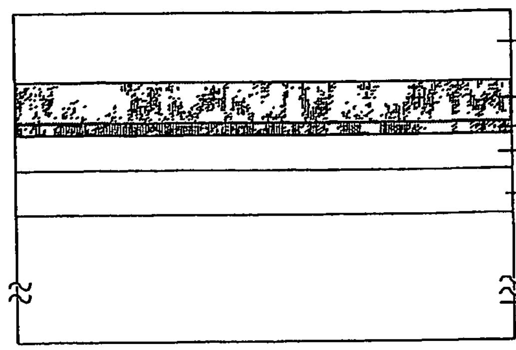


Figure 9: Schematic layout of dye/thin metal/ dielectric stack.

The second stack design (dye + thin metal) may have the problem of too low transmission near the optimum reflectivity. By adding a dielectric interference after the mirror this problem may be solved; the role of the dielectric I-layer is to "soften" the optical mismatch between the dye + thin metal stack and the polycarbonate substrate and thereby lower the reflection and raise the transmission.

Clearly, with three layers many combinations are possible. However, the only useful stack design is dye/thin-metal/I-layer, which can have high T, finite R, and sufficient absorption in the dye at the same time.

For this stack type, for the thin metal layer e.g. Ag, Au, Cu, Al or alloys thereof, or doped with other elements, can be used. In order to obtain a sufficiently transparent stack, the preferred thickness of the metal layer for this stack type is:

(9) $d_m \leq 25$ nm

As shown in Figure 10, the additional I-layer below the thin metal mirror indeed increases the stack's transmission and decreases its reflectivity, while the position of the R- and T-extrema stays (nearly) the same. The optimum dye layer thickness is (as in case 2) determined by the first maximum in reflection, which is given by Max(R) $\rightarrow \lambda / 2n_d (1 - \Delta)$, where $\Delta \sim 1/8$ to $1/4$ is a phase shift introduced by the metal. The preferred dye-layer thickness for this stack becomes:

(10) $\lambda / 8n_d \leq d \leq 5\lambda/8n_d$

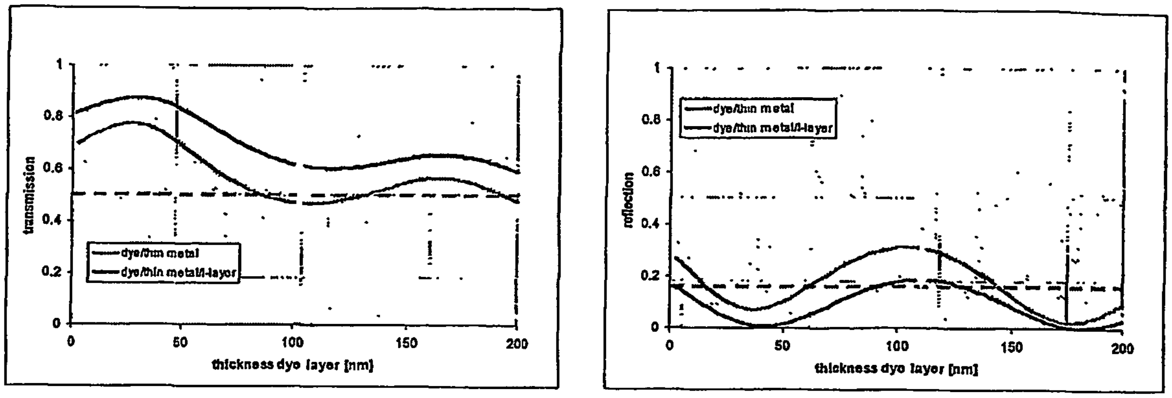


Figure 10: *The left-hand graph gives a comparison between the transmission of a dye/thin-metal stack ($n_d = 2.4$, $k_d = 0.1$, 10 nm Ag) and a dye/thin-metal/interference-layer stack ($n_d = 2.4$, $k_d = 0.1$, 10 nm Ag, $n_I = 2.1$, $d_I = 50$ nm) as a function of the dye's thickness. On the right is shown the reflection for these same stacks. The dashed red line indicates the lower limits allowed for R and T.*

It turns out that the relative increase in T that can be gained by the additional I-layer depends on the I-layer's refractive index and on the metal layer thickness, while the properties of the dye layer do not influence the relative increase of T. As shown in Figure 11, the useful range of refractive indices of the I-layer is

(11) $n_I \geq 1.8$

From

Figure 11 it can be derived what the minimal refractive index of the I-layer is for which an increase by a factor X in transmission of the bare dye/thin-metal stack can be gained. It follows that for an X-gain in transmission the I-layer's refractive index should be:

(12) $n_I \geq (X + 0.036*d_m - 1.025)/(0.0267*d_m + 0.005)$

Here, the metal layer thickness d_m is given in nanometers (note that the formula is an approximation in the range of n_I of 1.8 – 3). The X-factor can be calculated by dividing the required transmission of the stack (e.g. 50 %) by the transmission of the bare (without I-layer) dye/thin-metal stack (e.g. 38%). For example, if a transmission increase by a factor 50/38 = 1.3 is required for the bare dye/thin-metal stack having a metal layer of 15 nm thickness, the refractive index of the additional I-layer should by at least 2.0.

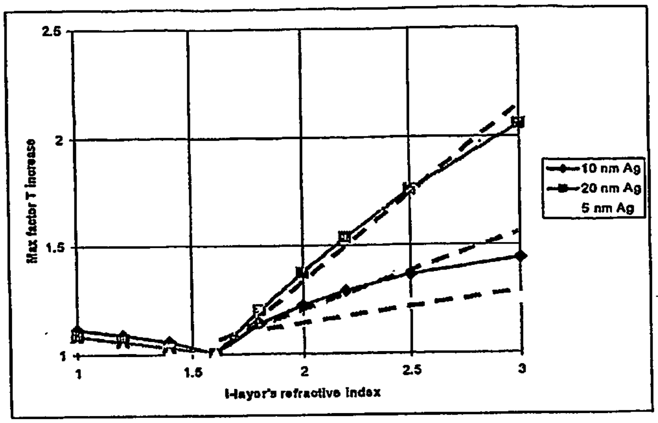


Figure 11: *Maximum factor (X) by which the transmission of a dye/thin-metal stack can be increased when adding an I-layer behind the metal as a function of the refractive index of the dielectric interference layer for three values of metal thickness. The dashed red lines indicate linear approximations of the functions $X(n_I)$ in the range $1.8 \le n_I \le 3.0$.*

The reflection and transmission of the stack are also periodic in the thickness of the lower-lying interference layer, with period $\lambda/2n_I$. Therefore, the I-layer thickness need not be larger than one period:

(13) $d_I \le \lambda/2n_I$

If the I-layer is intended to increase T (and decrease R) it's optimal thickness lies at the position of the first maximum in T which is located at $(1/2 - \Delta)*\lambda/2n_I$, with $\Delta \sim 1/8$. The preferred thickness of the I-layer then becomes:

(14) $d_{I,opt} = 3\lambda/16n_I$

For larger d_I the transmission decreases and the reflection increases again. If n_I is sufficiently large (see eq. 11), it is possible to keep the I-layer's thickness below the optimum value given above.
The useful thickness range of the I-layer then becomes:

(15) $d_I \le \lambda/4n_I$

Pro's: Flexible design, large range of R and T possible.

Preferred embodiments L0 stacks for DVD+R-DL

R_S is the reflection of the L0 stack as defined in annex D of the DVD read-only-disk book. To meet the DVD specification this should be in the range $18\% \leq R_S \leq 30\%$
T is the intrinsic transmission of the L0 stack, i.e. for the lower lying L1 stack having reflection $R_{S,L1}$ the effective reflection in a true dual-stack disc will be $T^2 * R_{S,L1}$.

stack 1: dye-only

59 nm azo-dye n=2.68, k=0.23 (mat sc. and eng. B79 (2001) 45.)
R_S=0.18, T=0.58

stack 2: dye on thin metal

(a)
100 nm MCC-1 azo dye: n=2.44, k=0.06 (JJAP 37 (1998) 2084.)
8 nm Ag n=0.16, k=5.34
R_S=0.21, T=0.53

(b)
100 nm MCC-1 azo dye: n=2.44, k=0.06 (JJAP 37 (1998) 2084.)
10 nm Au n=0.28, k=3.9
R_S=0.27, T=0.52

(c)
100 nm MCC-1 azo dye: n=2.44, k=0.06 (JJAP 37 (1998) 2084.)
10 nm Cu n=0.23, k=3.7
R_S=0.25, T=0.55

stack 3: dye on dielectric

67 nm MCC-1 azo dye: n=2.44, k=0.06 (JJAP 37 (1998) 2084.)
114 nm SiO_2 n=1.44
R_S=0.20, T=0.72

stack 4: dye on thin metal and dielectric

(a)
95 nm MCC-1 azo dye: n=2.44, k=0.06 (JJAP 37 (1998) 2084.)
10 nm Cu n=0.23, k=3.7
20 nm ZnS/SiO_2 (8:2)
R_S=0.19, T=0.62

(b)
95 nm MCC-1 azo dye: n=2.44, k=0.06 (JJAP 37 (1998) 2084.)
10 nm Ag n=0.16, k=5.34
55 nm ZnS/SiO_2 (8:2)
R_S=0.28, T=0.53

L1-stack design for DVD+R-DL

The lower L1 stack of a recordable dual-stack DVD disc should have high reflectivity at laser wavelength in order to be able to read back recorded data through the above L0 stack. To meet the DVD-ROM dual-layer (i.e. dual-stack) specifications the effective reflectivity of L1 should be in the range of 18% to 30%. If the L0 stack has a transmission at the laser wavelength of T, this means that the intrinsic reflection of L1 should be in the range $18/T^2$ % to $30/T^2$ %. Given typical transmission of L0 in the range 50% to 60% (see ID608519), this implies that L1's reflectivity should be 50% or more. This value already falls within the reflectivity-range specified for single-stack DVD+R discs. Thus in principle a "standard" single-stack DVD+R stack design can be used as the L1-stack. However, in the case of type 2 discs as proposed in ID608437, this implies that the dye is in direct contact with the adhesive for the spacer layer. This adhesive can possibly harm the dye, resulting in poor disc lifetimes. To circumvent this problem, two L1 stack types are proposed here which protect the dye from the adhesive. In order of appearance, these stacks are: thick metal layer + dye layer + dielectric layer, and thick metal layer + dye layer + thin metal layer.
The stacks proposed here are not restricted to use in DVD+R-DL and can be applied in any (multi-layer) organic-dye based optical recording medium.

For all L1 stack designs the thickness d_M of the thick metal layer should be:
(1) $d_M \geq 25$ nm
For the thick metal layer e.g. Ag, Au, Cu, Al or alloys thereof, or doped with other elements, can be used.

5. conventional stack

A conventional single-layer stack (dye on thick metal) can be used for L1 of type 1(see ID608437) discs.
The thickness of the dye having refractive index n_d should be in the range:
(2) $0 \leq d \leq 3\lambda/4n_d$

6. dielectric+dye+thick metal

Schematic layout of this stack design is given below in Fig 12

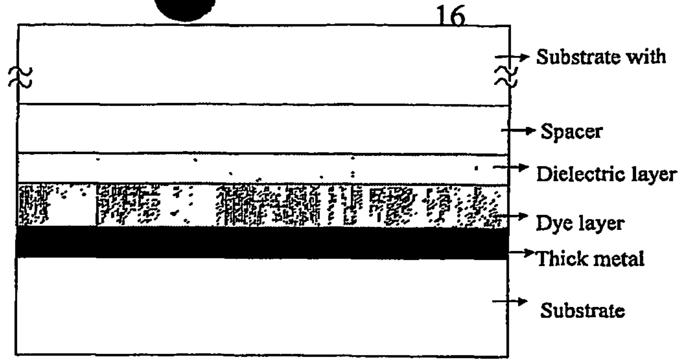


Figure 12: Schematic layout of L1 stack design: dielectric layer/ dye layer/ thick metal layer.

The thickness d of the dye having refractive index n_d should be in the range

(3) $0 \le d \le 3\lambda/4n_d$

The thickness d_I of the dielectric layer having refractive index n_I should be

(3) $0 \le d_I \le \lambda/n_I$

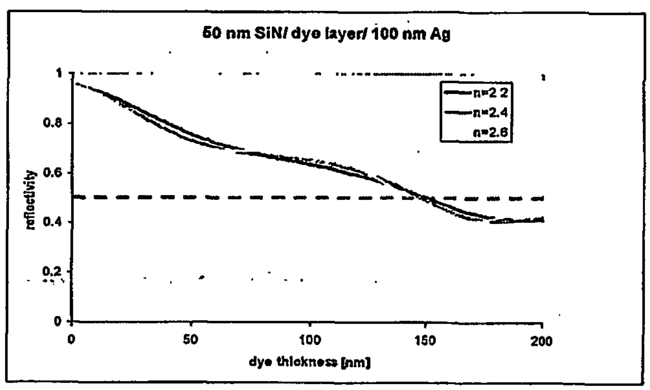


Figure 13: Intrinsic reflection of L1 stack design (dielectric/dye/mirror) as a function of the dye's thickness (k=0.1) for three values of the dye's refractive index n. The dashed red line indicates the 50% reflection level, which is expected to be a practical lower limit for the L1 intrinsic reflectivity.

2. thin metal+dye+thick metal

Schematic layout of this stack design is given below. (see also EP 0949 621 A1)

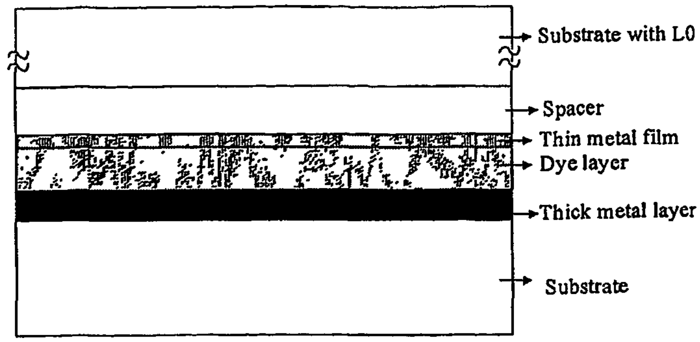


Figure 14: Schematic layout of L1 stack design: thin metal layer/ dye layer/ thick metal layer

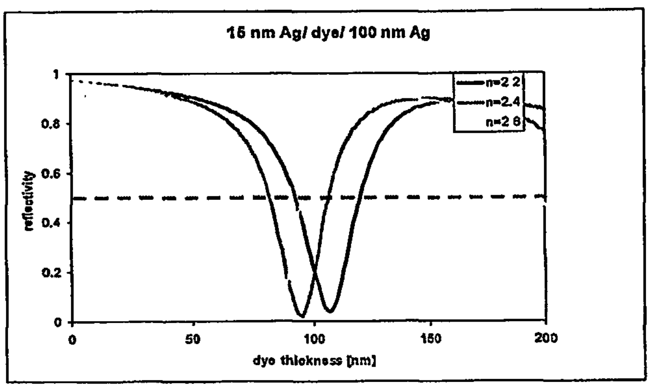


Figure 15: Intrinsic reflection of L1 stack design (thin metal/dye/mirror) as a function of the dye's thickness (k=0.1) for three values of the dye's refractive index n. The dashed red line indicates the 50% reflection level, which is expected to be a practical lower limit for the L1 intrinsic reflectivity.

The thickness d_{tm} of the thin metal film should be in the range

(2) $0 \leq d_{tm} \leq 25$ nm

For the thin metal layer e.g. Ag, Au, Cu, Al or alloys thereof, or doped with other elements, can be used.

The thickness d of the dye layer should be in the range

(3) $0 \leq d \leq 5\lambda/16n_d$

(4) $7\lambda/16n_d \leq d \leq \lambda/n_d$

Preferred embodiments L1 stacks for DVD+R-DL

R_S is the reflection of the L0 stack as defined in annex D of the DVD read-only-disk book. To meet the DVD specification this should be in the range $18\% \leq R_S \leq 30\%$
T is the intrinsic transmission of the L0 stack, i.e. for the lower lying L1 stack having reflection $R_{S,L1}$ the effective reflection in a true dual-stack disc will be $T^2 * R_{S,L1}$.

stack 6: dielectric layer, dye, thick metal

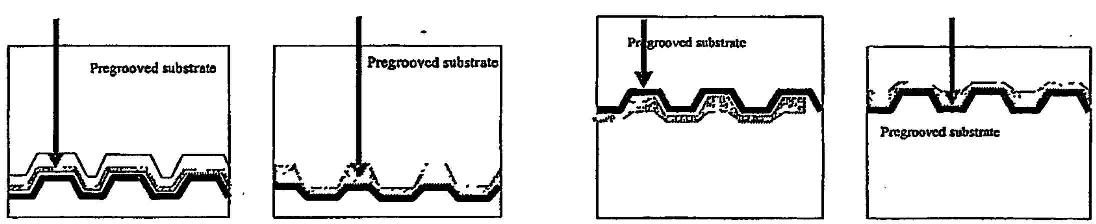
50 nm SiO_2 n = 1.44
130 nm azo-dye n=2.44, k=0.06 (mat sc. and eng. B79 (2001) 45.)
100 nm Ag n=0.16, k=5.34
R_S=0.73

stack 7: thin metal, dye, thick metal

15 nm Ag n=0.16, k=5.34
150 nm dye: n=2.44, k=0.06 (JJAP 37 (1998) 2084.)
100 nm Ag n=0.16, k=5.34
R_S=0.83

Push-pull sign reversal for organic DVD+R discs

For rewritable phase-change media recording is preferentially performed on grooved sections closest to the plane of incidence of the laser light. Due to the levelling effect of a spin-coated dye layer, organic write-once media have thicker recording layer in the grooves than on the lands so that recording is optimal in the filled grooves. In case of CD and DVD single stack, where the laser light is substrate-incident, geometrically the preferred recording position for R and RW media are equal: *on*-groove (nearest to plane of incidence). For DVD dual stack, however, the L_1 type 2 stack is reversed and as a result this type of write-once DVD-R DL discs require *in*-groove recording (away from plane of incidence). This means that for the type 2 DVD+R DL system the radial tracking should switch between on-groove for the L_0 stack and in-groove for the L_1 stack. From the drive perspective, this is a very unfavourable situation.
It is proposed to tune the groove depth and dye-layer thickness on land and groove sections of a DVD-R DL L_1-stack in such a way that the push-pull is reversed with respect to a DVD+R single stack or DVD+R DL L_0-stack. As a result, without any modification in the drive, a DVR-R DL L_1 is automatically tracked *in*-groove, The required layer thickness can be obtained from a straight-forward calculation.



Rewritable CD/DVD on-groove | Write-once CD/DVD on-groove | Rewritable DVD+R DL Lo stack on-groove | Write-once DVD+R DL L1 stack in-groove (type 2)

Fig. 16: RW and R recording stacks for CD/DVD (normal stack) and DVD (L0 and L1 stack).

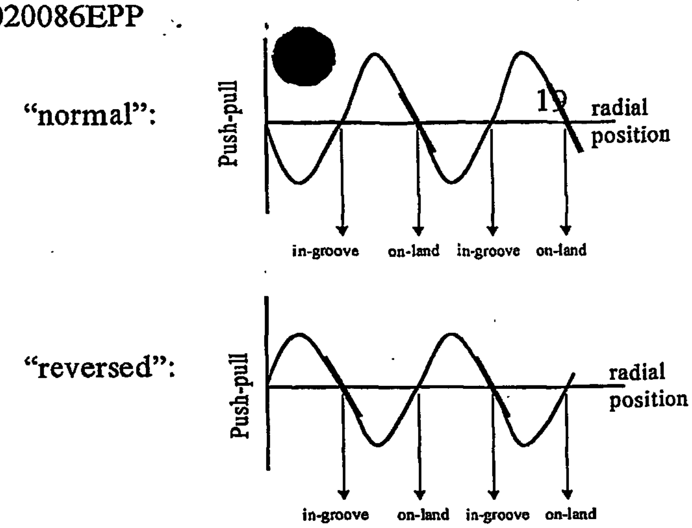


Fig. 17: Comparison between "normal" and "reversed" push-pull. Blue lines denote the slope from which the radial tracking system derives the servo-signals.

Sign of push-pull

In the following a "land" denotes the section closest to the plane of incidence of laser light and a "groove" denotes a section lying away from this plane of incidence. Thus, on-groove translates to land and in-groove translates to groove.

The sign of the push-pull signal equals (or opposites, matter of definition) the sign of the difference $\Delta\varphi = \varphi_G - \varphi_L$ between the phase φ_L of the reflection from land sections and the phase φ_G of the reflection from groove sections. For DVD-RW, the stack structure on land and groove are equal and, consequently, the phase from the lands always lags behind the phase of light reflected from the grooves: $\Delta\varphi = -4\pi n_0 g/\lambda$ (n0 substrate's refractive index, g groove depth, λ laser wavelength). In our definition this leads to a negative push-pull for groove depths less than 90° (<65nm). For DVR+R, the layer thickness on land and groove differ, and interference effects must be taken into account when calculating the phase difference. The easiest case to calculate is for a dye-layer sandwiched between two semi-infinite media (e.g. cover and polycarbonate, or cover and metal mirror).

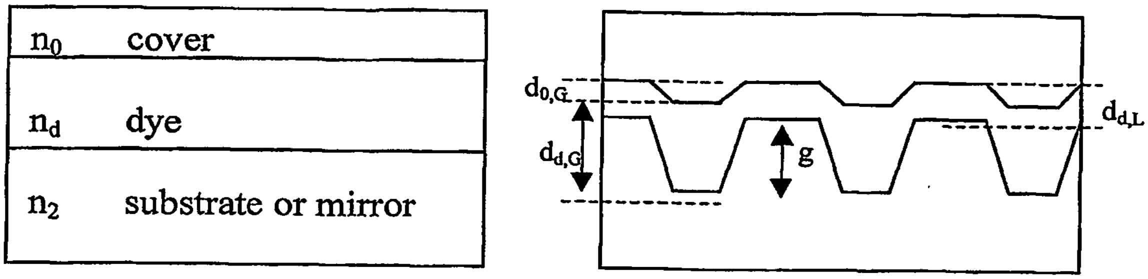


Fig. 18: Definition of thickness of layers and optical constants.

$$L = \frac{d_{d,G} - d_{d,L}}{g}$$

$$r = \frac{r_{01} + r_{12}\exp(-2i\phi_1)}{1 + r_{01}r_{12}\exp(-2i\phi_1)} \cdot \exp(-2i\phi_0)$$

$$r_{01} = \frac{n_0 - n_d}{n_0 + n_d}, \quad r_{12} = \frac{n_d - n_2}{n_d + n_2}$$

$$\phi_0 = \frac{2\pi\, n_0 d_0}{\lambda}, \quad \phi_1 = \frac{2\pi\, n_d d_d}{\lambda}$$

For the lands $d_d = d_{d,L}$ and $d_0 = 0$, while for the grooves $d_d = d_{d,G}$ and $d_0 = d_{0,G}$, see figure 21.

In figures 19 and 20 we give two examples (dye-only and dye on Ag mirror, respectively) for two values of levelling (L=1 and L=0.5) which sets the thickness difference between land and groove (see above).
The calculations can be repeated for more complicated stacks.

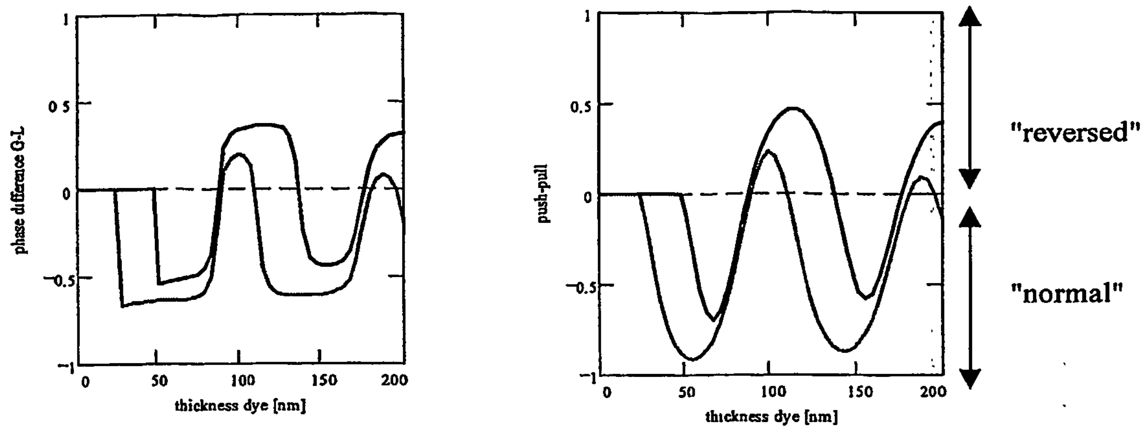


Figure 19: Phase difference and push-pull for cover/dye/polycarbonate with 50 nm groove depth. Black lines L=1, red lines L=0.5

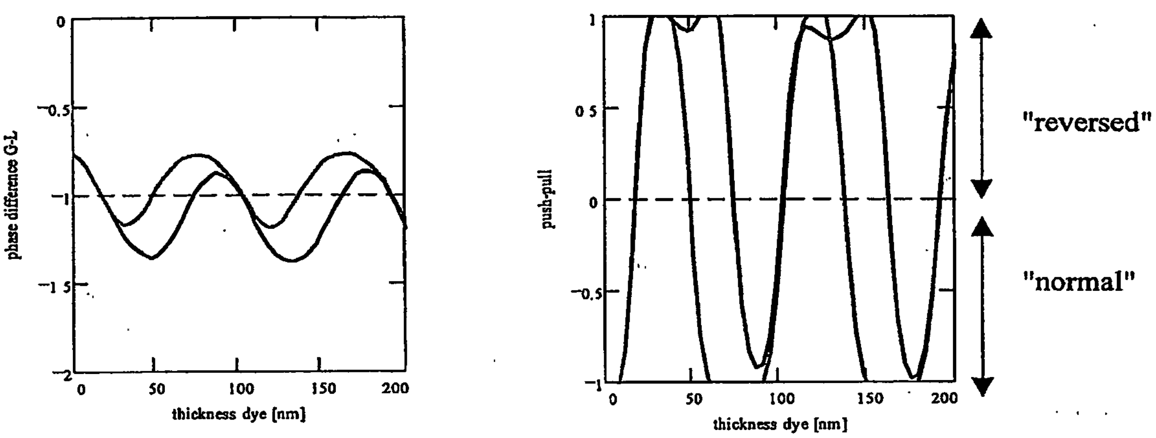


figure 20: Phase difference and push-pull for cover/dye/silver-mirror with 50 nm groove depth. Black lines L=1, red lines L=0.5.

Transparent heat-sink in combination with organic dyes: L0-stack design for DVD+R-DL

The upper L0 layer of a recordable dual-layer DVD disc should have high transparency in order to be able to address the lower lying L1 layer. The most obvious way to arrive at a transparent stack is by decreasing the thickness of the metal mirror of a conventional single layer dye stack. In the single layer dye stack, the metal mirror not only has an optical function but also serves as a means to take away the heat in the dye layer during the recording process. If the heat stays too long in the recording layer, the pit formation process can be deteriorated. A very thin metal layer, required for transmission, will have less cooling capacity. This can lead to poor recording performance. In this

It is proposed to apply a transparent heat sink in the L0 recording stack.
This will lead to improved recording performance.
The types of L0 stack that can be used have been disclosed earlier (L0 stack 2 and L0 stack 4). In these two stack types a dielectric layer is present to tune the reflection and transmission values. Typical dielectric materials used are $ZnS\text{-}SiO_2$ or SiO_2, etc. These non-conducting dielectric materials have poor heat conductivity, typically < 1 W/mK. An improved heat sink function can be obtained by replacing the dielectric with for instance ITO, HfN , or AlON which have a heat conductivity > 1 W/mK (ITO has about 3.6 W/mK). These materials have optical constants close to typical dielectrics ($n \sim 2$, $k < 0.05$), therefore optical stack designs similar to stack 4 can be used.

Embodiments

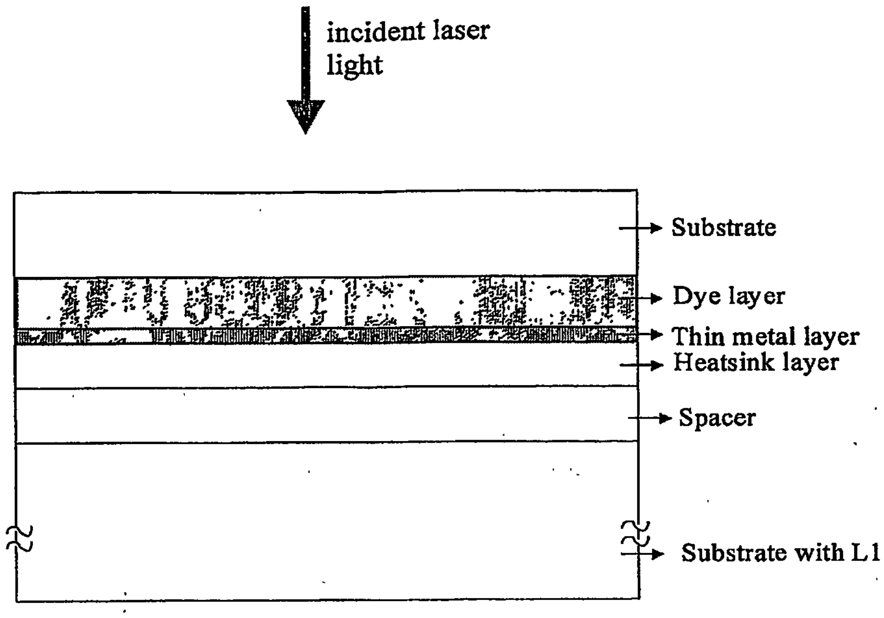


Figure 21: Schematic layout of transparent recordable optical stack incorporating a transparent heat sink layer

Example of stack 1 (see figure 21): 95 nm dye/ 8 nm Ag/ 50 nm ITO → R = 22%, T = 59%

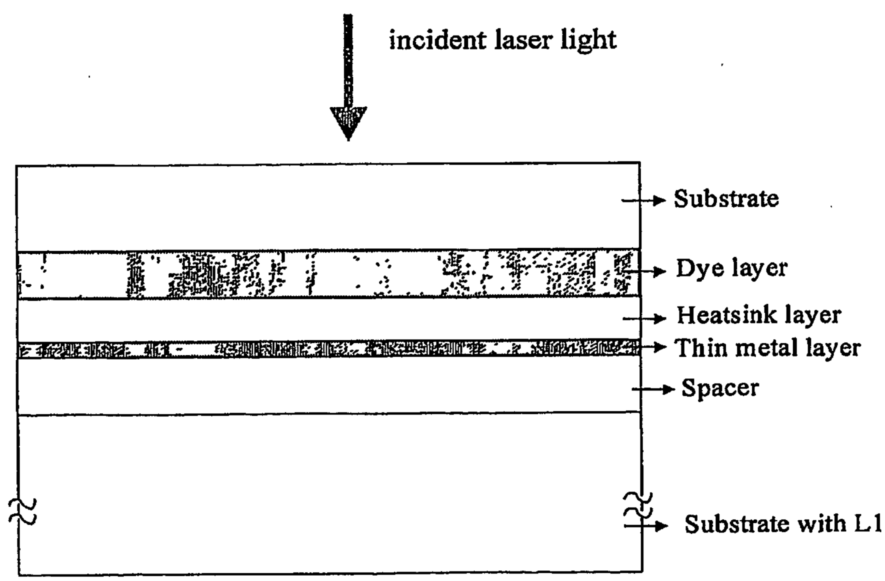


Figure 22: Schematic layout of a transparent recordable optical stack incorporating a transparent heat sink layer.

Example of stack 2 (see figure 22): 110 nm dye/ 60 nm ITO/ 8 nm Ag → R = 19%, T = 55%.

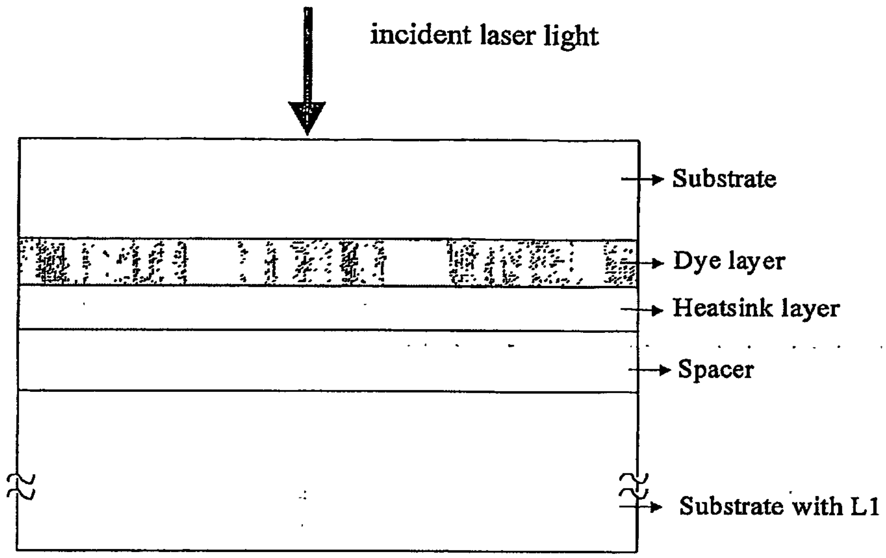


Figure 23: Schematic layout of a transparent recordable optical stack incorporating a transparent heat sink layer.

Example of stack 3 (see figure 23): 150 nm dye/ 45 nm HfN → R = 19%, T = 63 %.

Optical constants used in the calculations: dye n=2.44, k=0.06; Ag n=0.16, k=5.34, ITO n=2.01, k=0.017, HfN n=2.8, k=0.02

Claims:

1. A dual-stack optical data storage medium for write-once recording by means of a focused laser-light beam emanating from a laser-light beam source, said medium having at least one substrate carrying:
-a first recording stack, named L_0, comprising a recordable type recording layer, said first recording stack being present at a position closest to the focused laser-light beam source,
-a second recording stack, named L_1, comprising a recordable type recording layer,said second recording stack being present at side of the first recording stack opposite from the side of the laser-light beam source during recording,
-a transparent spacer layer between the first and the second recording stack having a thickness larger than the depth of focus of the focused laser-light beam,
wherein the first and second recording stacks further comprise auxiliary layers for achieving that the first and second recording stacks have the proper optical reflection and transmission levels for said laser-light beam.

2. A multi-stack optical data storage medium for write-once recording by means of a focused laser-light beam emanating from a laser-light beam source, said medium having at least one substrate carrying:
-a first recording stack, named L_0, comprising a recordable type recording layer, said first recording stack being present at a position closest to the focused laser-light beam source,
-a second recording stack, named L_1, comprising a recordable type recording layer, said second recording stack being present at side of the first recording stack opposite from the side of the laser-light beam source during recording,
-a transparent spacer layer between the first and the second recording stack having a thickness larger than the depth of focus of the focused laser-light beam,
-a further recording stack, named L_n where n is an integer number larger than 1, comprising a recordable type recording layer, said further recording stack being present at a side of the second recording stack opposite from the side of the laser-light beam source during recording, and
-a further transparent spacer layer for separating said further recording stack from the L_{n-1}-stack,
wherein the first, second and further recording stacks further comprise auxiliary layers for achieving that the first and further recording stacks have the proper optical reflection and transmission levels for said laser-light beam.

PCT Application

EP0250001